North American Journal of Fisheries Management 4:371–374, 1982

Avoidance of Suspended Sediment by Juvenile Coho Salmon

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ABSTRACT

Some water quality standards established by the states permit only minor increases in suspended sediment when background turbidity is low, allow greater absolute increases as background levels rise, and do not consider acclimation of stream biota to high turbidity. Juvenile coho salmon (*Oncorhynchus kisutch*) were subjected to experimentally elevated concentrations of suspended sediment and did not avoid moderate turbidity increases when background levels were low, but exhibited significant avoidance when turbidity exceeded a threshold that was relatively high (>70 NTU) and was varied according to previous suspended sediment exposure.

Although the biological impact of sediment deposited in stream gravels has received considerable attention in the Pacific Northwest (Burns 1970, 1972; Cederholm and Lestelle 1974; Iwamoto et al. 1978), relatively little is known about the effects of suspended sediment on stream-dwelling salmonids. However, state water quality regulations governing sediment-related, non-point source pollution often specify allowable increases in suspended loads, usually measured by turbidity, rather than setting limits on sediment deposited in the stream bed. The objective of our study, therefore, was to examine the influence of suspended sediment from logging-road use on the behavioral responses of juvenile coho salmon (*Oncorhynchus kisutch*) that frequently inhabit headwater streams influenced by forest management activities in the Pacific Northwest. Our experiment was designed to test (a) the threshold turbidity level eliciting avoidance, and (b) modification of behavioral responses by acclimation to chronic low levels of fine sediment. Applications of the results to fish-stocking programs and water quality regulations are discussed.

METHODS

Experimental avoidance-preference trials were conducted in the laboratory using young-of-the-year coho salmon collected from Huckleberry Creek, a small tributary of the Deschutes River, Washington. This stream was picked because it received little sediment input and the fish had had little exposure to turbid water. In the laboratory, test fish were divided into two groups; one group was maintained in clear water of less than 0.3 nephelometric turbidity units (NTU), and the other group was held in slightly turbid water. Fine sediment was collected from a catchment basin next to a heavily used unpaved road. A small amount of sediment was added to one holding tank and kept in suspension by aeration and periodic stirring. The 2–15 NTU acclimation level approximated winter base-flow turbidities observed in other tributaries of the Deschutes River system.

After being held and fed for at least 3 weeks, 10 individuals from one or the other acclimation group were placed into a continuous-flow rectangular aquarium that was plumbed to permit the addition of suspended sediment to one half while leaving the other half clear. The aquarium was similar to the design of Scherer and Nowak (1973), except that the dimensions of the chamber were 120 × 17 × 18 cm. Both the clear and turbid water sources were maintained at identical temperatures (12.5–13.5 C) and aerated to keep oxygen levels near saturation. Average weight of the fish ranged from 0.7–2.0 g during the trials.

Both halves of the chamber received clear water during the first 30 minutes of the trial and the preference of the fish for either side was recorded six times during this period. Suspended sediment then was introduced into one-half of the chamber (the half was varied at random) and the fish were allowed to choose between the turbid and clear halves for an additional 30 minutes. Their locations were noted 12 times during these periods. In instances where individuals were partially immersed in the turbid water, decisions were based on the locations of the fishes' heads relative to the suspended sediment–clear water interface.

Table 1. Behavioral response by juvenile coho salmon to the introduction of suspended sediment, as measured by the change in number of fish observed in the treated half of the test chamber before and after sediment addition. Positive numbers denote increased preference for the treated portion after sediment addition; negative numbers denote avoidance.

Turbidity (NTU)	Average per cent change
Clear-water acclimation	
10	+9
16	−5
19	−9
41	−6
42	+1
53	−7
70	−13[a]
97	−16[a]
158	−26[a]
184	−12[a]
Turbid-water acclimation (normal behavior)	
10	+1
16	+3
81	−3
92	+3
106	−15[a]
124	−34[a]
126	−26[a]
160	−19[a]
179	−15[a]
Turbid-water acclimation (fright behavior)	
42	+13[a]
99	+15[a]
104	+26[a]
195	+37[a]

[a] $P < 0.05$.

An unpaired Student's *t*-test was used to compare the number of fish occupying only the treatment half before and after sediment was added. The null hypothesis was that turbidity increases would have no effect on the number of fish choosing to remain in the treatment side of the chamber. With one important exception, test fish showed no obvious signs of grouping behavior during the trials.

Results

Juvenile coho salmon that were acclimated to clear water did not exhibit significant sediment avoidance until the turbidity reached 70 NTU (Table 1). Although fish in most experimental trials reacted to the addition of sediment by avoidance at the outset, after about 5 minutes they began to pass back and forth between the treated and control portions of the chamber. After a few investigative forays, individuals usually settled on one side or the other. Responses to turbidity increases were not always in direct proportion to the sediment concentration. Even after the significant threshold had been exceeded, the extent of avoidance was erratic. For example, greater avoidance was observed at 158 NTU than at 184 NTU.

Behavior of coho salmon acclimated to slightly turbid water fell into two categories—normal swimming behavior and fright response. Experimental groups exhibiting normal behavior reacted to the introduction of sediment in a manner similar to fish acclimated to clear water, except that the turbidity avoidance threshold increased to approximately 100 NTU (Table 1). Fright behavior was actually observed in more than four trials but the first two times it was noted the trial was aborted and the fish discarded. The behavior pattern consisted of rapid darting movements, huddling together, and attempting to hide in corners. This behavior has been observed previously in juvenile coho salmon in experimental stream systems (Mason and Chapman 1965) and has been called "fright huddle." In every trial where fright behavior was exhibited by the fish acclimated to turbid water, they preferred the turbid portion of the chamber and this preference increased with higher turbidity levels. Test fish tended to respond as a group. Where fright behavior was observed, it occurred in virtually all individuals. This was the only instance during the trials where grouping behavior was obvious. We do not know what elicted the fright response among coho salmon acclimated to turbid water except to speculate that it was related to the sudden transfer into an environment where cover was lacking. This conclusion resulted from the observation that many fish quickly darted into the turbid half of the chamber upon removal of the one-way observation window at the end of a trial.

Discussion

Suspended sediment levels avoided by coho salmon in the trials were below acute lethal thresholds for salmon and trout (Herbert and Merkens 1961). However, feeding effectiveness may be impaired within the 70–100 NTU range (Alabaster 1972; Sykora et al. 1972) and the fish may have been avoiding turbid water in order to maintain a view of potential food items. For juvenile coho salmon, overall visibility, flotation, and background contrast are key factors in food selection (Mundie 1971). Noggle (1978) reported that predation on caddis larvae by coho salmon decreases to zero at about 300 mg/liter suspended sediment but, given a choice between clear water and "moderate" turbidity, coho salmon tended to prefer slightly turbid conditions. We found no evidence of a significant preference for slightly turbid water (10–20 NTU) in any of our experiments, including fish acclimated to 2–15 NTU. However, in certain instances, water having higher turbidity was sought for cover when the fish were frightened, and Gradall and Swenson (1982) have recently noted that brook trout (*Salvelinus fontinalis*) rely less on overhead cover and become more active at moderate turbidity levels compared to clearer conditions.

Heavy road use during periods of moderate to intense precipitation can cause turbidity increases in streams (Reinhart et al. 1963; Wald 1975; Wooldridge 1979) although levels above 100 NTU usually exist for only short durations (Brown and Krygier 1971; Reid 1981). Occasions where exceptionally high turbidities occur may be sufficient to cause some movement into areas with clearer water. In recent years, a large number of streams in the Pacific Northwest have been stocked with coho salmon fry in order to ensure adequate seeding and avoid the expense of hatchery rearing. These fish usually have been held in clear water prior to release. The results of our experiment suggested that coho fry should not be stocked when streams are carrying a high load of suspended sediment. Rather, they should be released when streams are clear or slightly turbid so that the fish have time to adjust to relatively low levels of suspended sediment and thus raise their tolerance to periodic turbidity increases during storms.

State water quality standards for suspended sediment often limit increases to some fraction of the background levels or to a fixed turbidity limit above background. For example, Oregon limits increases to "no more than a 10% cumulative increase in natural stream turbidities." Washington's water quality regulations state: "Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10% increase in turbidity when the background turbidity is more than 50 NTU." These regulations, in effect, permit only slight increases when background levels are low and larger increases as background levels rise. Although suspended sediment standards are designed to protect both spawning and rearing periods, and to minimize impacts on periphyton and invertebrates, the results of this study indicated that moderate turbidity increases over low background levels may not cause avoidance by juvenile coho salmon. However, acceptance of this conclusion should await testing of controlled, sediment-addition studies in natural streams.

Acknowledgments

We thank J. N. Fisher and C. R. Patterson for technical assistance, and C. B. Schreck, R. L. Beschta, and L. Berg for reviewing the manuscript.

References

ALABASTER, J. S. 1972. Suspended solids and fisheries. Proceedings of the Royal Society of London B. 180:395–406.

BROWN, G. W., AND J. T. KRYGIER. 1971. Clear-cut logging and sediment production in the Oregon Coast Range. Water Resources Research 7:1189–1198.

BURNS, J. W. 1970. Spawning bed sedimentation studies in northern California streams. California Fish and Game 56:253–270.

BURNS, J. W. 1972. Some effects of logging and associated road construction on northern California streams. Transactions of the American Fisheries Society 101:1–17.

CEDERHOLM, C. J., AND L. C. LESTELLE. 1974. Observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington, 1972–73. University of Washington, Fisheries Research Institute, Final Report FRI-UW-7404, Seattle, Washington, USA.

GRADALL, K. S., AND W. A. SWENSON. 1982. Response of brook trout and creek chubs to turbidity. Transactions of the American Fisheries Society 111:392–395.

HERBERT, D. W. M., AND J. C. MERKENS. 1961. The effect of suspended mineral solids on the survival of trout. International Journal of Air and Water Pollution 5:46–55.

IWAMOTO, R. N., E. O. SALO, M. A. MADEJ, AND R. L. MCCOMAS (editors). 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria. U.S. Environmental Protection Agency, Region 10, EPA 910/8-78-048, Seattle, Washington, USA.

MASON, J. C., AND D. W. CHAPMAN. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. Journal of the Fisheries Research Board of Canada 27:1215–1224.

Mundie, J. H. 1971. The diel drift of Chironomidae in an artificial stream and its relation to the diet of coho salmon fry, *Oncorhynchus kisutch* (Waulbaum). Canadian Entomologist 103:289–297.

Noggle, C. C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. Master's thesis, University of Washington, Seattle, Washington, USA.

Reid, L. M. 1981. Sediment production from gravel-surfaced forest roads, Clearwater basin, Washington. Master's thesis, University of Washington, Seattle, Washington, USA.

Reinhart, K. G., A. R. Eschner, and G. R. Trimble, Jr. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. U.S. Department of Agriculture, Forest Service Research Paper NE-1, University Park, Pennsylvania, USA.

Schumm, S. A. 1977. The fluvial system. Wiley-Interscience, New York, N.Y., USA.

Scherer, E., and S. Nowak. 1973. Apparatus for recording avoidance movements of fish. Journal of the Fisheries Research Board of Canada 30: 1594–1596.

Sykora, J. L., E. J. Smith, and M. Synak. 1972. Effect of lime neutralized iron hydroxide suspensions on juvenile brook trout (*Salvelinus fontinalis,* Mitchell). Water Research 6:935–950.

Wald, A. R. 1975. The impact of truck traffic and road maintenance on suspended-sediment yield from a 14-foot standard forest road. Master's thesis, University of Washington, Seattle, Washington, USA.

Wooldridge, D. D. 1979. Suspended sediment from truck traffic on forest roads, Meadow and Coal Creeks. Department of Ecology, 79-5a-3, Olympia, Washington, USA.